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# *Operation Manual for the CO<sub>2</sub> Laser System*

ANDERS DANIELS

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Departments of Aerospace Engineering  
Meteorology and Oceanography

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THE UNIVERSITY OF MICHIGAN  
COLLEGE OF ENGINEERING  
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Final Report

OPERATION MANUAL FOR THE CO<sub>2</sub> LASER SYSTEM

by

ANDERS DANIELS  
ORA Project 004780

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### Abstract

This report outlines a detailed complete step by step procedure for the alignment and successful operation of the 10.6 m CO<sub>2</sub> laser system used for the study of Mandel'shtam-Brillouin Scattering.

## I. Introduction

The CO<sub>2</sub> laser system used for the study of Mandel'shtam-Brillouin scattering was required to be of high optical quality and high power output. The design of this laser system is described in the report on the M-B scattering study.<sup>1</sup> The complete step by step procedure of putting this system in operation is described in this report.

If the system is operated regularly, realignment should not be necessary each time it is turned on. In this case, it should be sufficient to carry out the procedures described in sections II to IV below.

## II Operation of the Laser System

### A. Cooling System

1. Fill one sink upstairs with water.
2. Connect water hose to the tap upstairs, turn on water.
3. Determine that cooling water is running through system to the downstairs sink.
4. Determine that there are no leaks, particularly at the mirrors of the oscillator. If leaks appear, dismantle mirror mount and replace the rubber ring between the mirror and its mount and realign the mirror.
5. Go upstairs and disconnect (under the water) the hose at the copper tube joint. This arrangement will reduce the negative effects of variations in the water pressure and air bubbles in the water.
6. Adjust water flow so that the level does not go below the top of the sink, excess water drains to the neighbour sink.

### B. Vacuum system (see figure 1)

1. Connect a vacuum gauge (borrowed from Prof. D. Bach in Nuclear Engineering), to the outlet at the brass manifold just outside the acoustic box.

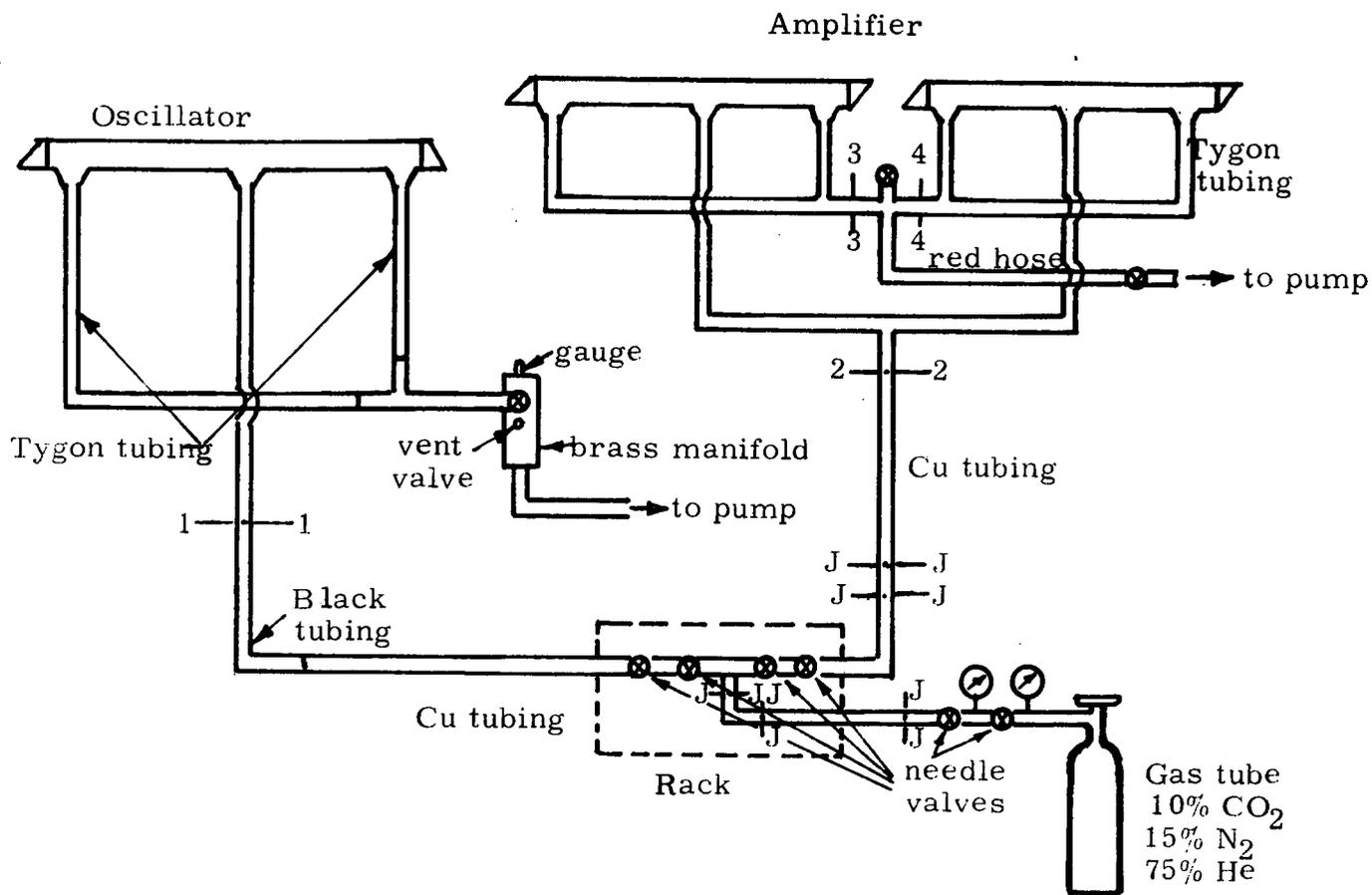


Figure 1. Vacuum system

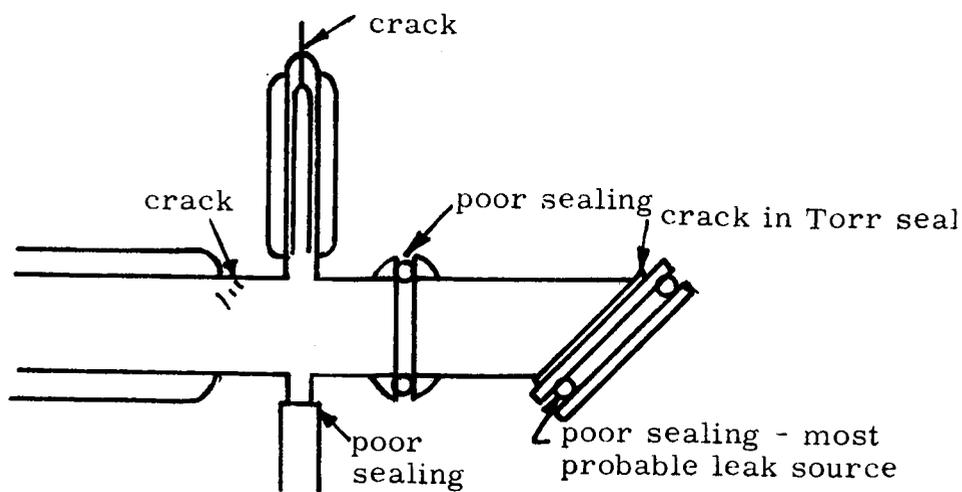


Figure 2. Probable leak sources at the Brewster ends

2. If the pressure is less than 200 microns, the vacuum in the system is O. K. Although the system will still function if the vacuum is as high as 200 microns, it is possible to get it as low as 40 microns.
3. If the pressure is greater than 200 microns:
  - a. Close off the connecting line from the gas supply by clamping the black hose to the laser oscillator (1. in Fig. 1) and the transparent one to the amplifier (2. in Fig. 1). Have the two close off valves closed. If the pressure goes down to 200 micron: open one and then the other to determine where the leak is. The most probable leak sources are the soldered copper joints, (J in Fig. 1). Resolder the joints using the small torch.
  - b. If the leak is not found by the previous arrangement, close off the connecting valve (at the side of the bench) for the amplifier. If pressure goes down, find out which of the two amplifiers is leaking by closing off the appropriate red thick vacuum tube (3 and 4 in Fig. 1). The most probable source of leak is at the Brewster ends (see Fig. 2). Check this by the following procedure:
    - i.) Replace the window with a plastic piece, if the vacuum is O. K. put the window back, wiggle it to make sure it covers the end, clean o-ring.
    - ii.) If i.) does not correct the leak, take the entire Brewster mount away and replace it with a piece of plastic. If there is a good vacuum now, clean the o-ring and put more "Torr seal" on the mount.
    - iii) If i) and ii) do not reveal the leak, there is probably a small crack in the tube, which is hard to find. You can use leak seal to find it, and use "Torr seal" for sealing the crack. Also check the tubing connections and replace the o-ring, it might have a crack. There might also be cracks in the sections not having a Brewster mount.

Check all sections by pumping section by section, sealing the ends with plastic pieces. Turn the sections slightly to insure a good vacuum connection. Start checking sections at one end, add one at a time and pump down.

- c. If the leak was not found in a. and b. above, check the oscillator by closing the black valve on the manifold. If the pressure goes down, check first the salt windows (use gloves) for cracks and poor sealing and secondly the o-rings at the mount. Use plastic piece as in b above.
- d. If the pressure still does not go down there probably is poor sealing in the vacuum "container" above the pump or the tubing to the system. With the two valves closed off to the amplifier and oscillator, the pressure reading on the indicator at the pump should be less than 20 microns.
- e. See that there are no leaks in the system "behind" the two closed off valves on the racks and the gas container by opening these valves. Then read the equilibrium pressure, it should still be less than 200 microns. If not, check and resolder all joints, start with those outside the cabinet.

C. Discharge system:

Laser oscillator

Connect a 20 kv, 32 mA Sornensen power supply, + polarity to the ripple filter in the rack (remove top cover, instruction book in the cabinet). Ground chassis of the power supply. Connect the output from the filter to the top on the tube in the current stabilizer. Note that the lead from the side of the stabilizer is connected to the top boards in the resistor cabinet. Note that the total resistance of each board is about 250 K Ohm.

Test current stabilizer (figure 3) without high voltage by turning on the low voltage on the rack (use plastic covered switch) The tube should light up and the mA meter reading should change from 0 to 12 mA when the dial is moved upward from 0. The upper stabilizer (for the laser oscillator) never gave any trouble. Before turning on high voltage on the power supply:

1. Note that the cooling water is running.
2. Note that the pressure  $\leq 200$  micron on the meter connected to the manifold.
3. Determine that the end of the amplifier is not covered e. g. by a protective glove).
4. Note that low power is on on the current stabilizer and the dial is at full scale.
5. Note that the black valve on the brass manifold is opened  $1/8$  of a turn so that the two red marking lines match.

Turn on "power on" switch on the power supply and move the high voltage dial until current is about 30 mA and both arms on the oscillator have a discharge. The discharge should appear as a bluish light to both end electrodes. If only one arm discharges turn the voltage up and down until both arms discharge.

Turn on the valve at the top of the gas cylinder. The pressure on the second gauge should read  $\sim 60$ . Open the big "close off" valve completely, do not turn the needle valve, it is preset, and adjust the voltage upward so that the current meter reads about 30 mA all the time. When the gas glow is at equilibrium after about one minute the voltage should be about 17 kV. Adjust the voltage so that the mA indicator is off scale and the mA meters on the rack are reading 18 mA each (approximately). Turn the dial on the stabilizer backwards

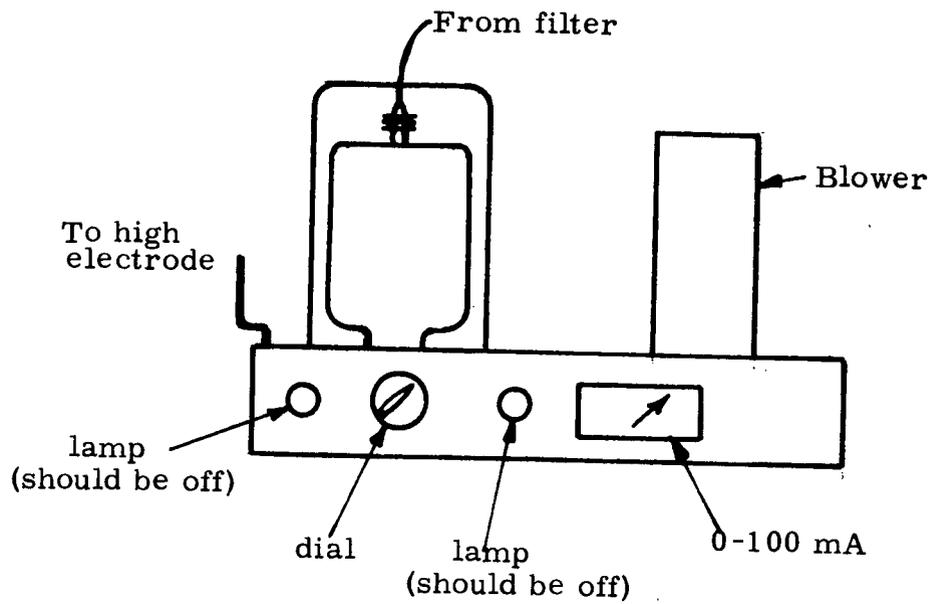


Figure 3. Current stabilizer

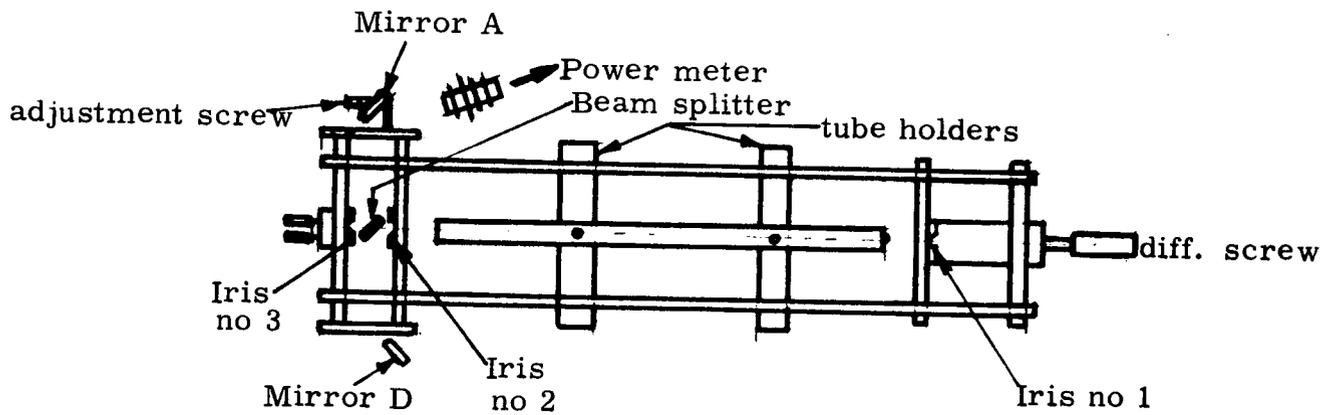


Figure 4. Laser oscillator (top view)

until the current starts to decrease, at this point the stabilizer is working.

If the current is different in the two legs, adjust the rheostat in the lower resistor board. The discharge should now have a reddish color. Test for the laser beam by putting a piece of paper in the path. It should burn a hole. If not, see alignment. If it burns a hole go to the section following next section.

D. Alignment of the laser oscillator (figure 4)

To align the system it is necessary to have a laser power meter to measure the effects of a mirror movement. The laser power meter can be borrowed at Willow Run (Dwain Carmer) or at Packard Hanger (Leo Larsen, ext. 555).

If the discharge is running in both arms at 32 mA and 17 kV and has a reddish color but no lasing is evident as measured by the power meter or a piece of paper, carry out steps 1 to 4 below.

1. Put the power meter close to the oscillator.
2. Make sure nothing is blocking the beam between the laser and the power meter.
3. Check to see that all three irises are open - not completely - they should already be adjusted for single mode running.  
Caution: Use wooden stick to open the aperture if closed, since high voltage can leak through to the adjusting rod.
4. Write down the reading of the micrometer on the fixed side and slowly turn one at a time, 1/10 of a turn at each time, use a pair of pliers since the micrometers are adjusted very tightly. Check with a piece of paper to see that the beam actually enters the center of the power meter.

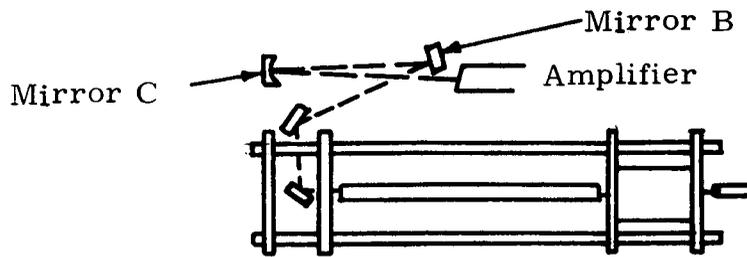


Figure 5. Mirror Geometry

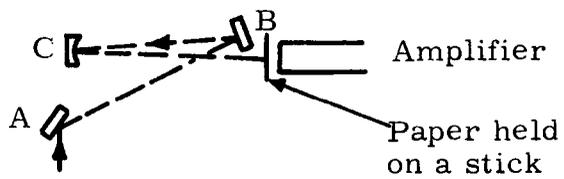


Figure 6. Centering the Amplifier

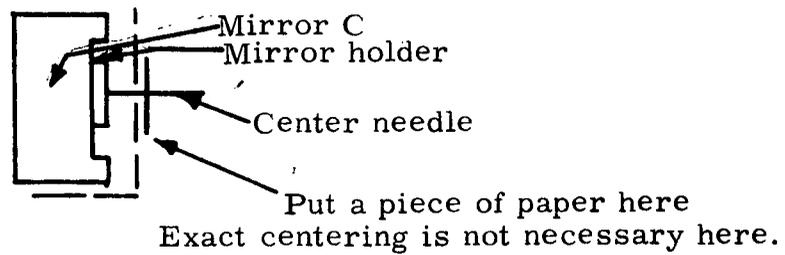


Figure 7. Mirror cover for C.

When the power meter starts to register - use lowest scale first:

1. Align the power meter by turning or tilting it to give maximum reading.
2. Block off the aperture mirror "D" with a piece of aluminum.
3. Adjust the two micrometers at the fixed mirror for max reading.
4. Adjust the micrometer on the movable end to max power.
5. Adjust the differential screw for max power.
6. Adjust the two tube holders for max power. Max power should now be about 3 Watts. If not - do 1. through 6. again.

A hole burnt in a paper should now be circular and only have one spot. This indicates that the laser is running in single mode.

7. Remove power meter and adjust mirror A and B so that the beam hits the center of the spherical mirror C. To check this, place the aluminum mirror cover with the needle in the center (should now be beside the mount in the box) (see figure 5).

Put a piece of paper over the needle and note the place of the burn spot and adjust it horizontally at mirror A and vertically at mirror B (by slightly pushing this mirror with a yard stick).

8. Adjust aperture mirror D by removing the aluminum piece obstructing the beam and observe the additional burn spot on the paper at the spherical mirror mount. Adjust the screws on mirror D until the additional burnspot is close to the center of the other burn spot. If no additional burn spot is observed on the paper, trace the spot at mirror A and adjust it.
9. Adjust mirror C by removing the cover and putting a piece of paper on a yard stick and make sure the beam is approximately in the center of the amplifier tube (Figure 6).

#### E. Laser amplifier

Before turning on high voltage to the laser amplifier:

1. Make sure nothing is blocking the beam at the end of the amplifier and that the chopper blade does not block the beam.

2. Make sure the power supply is grounded on the side of the cabinet.
3. Set the supply to + polarity.  
Set the filter to + polarity. (under the instrument panel)
4. Connect the high voltage line to the stabilizer as described for the oscillator.
5. Check the connections to the two high center electrodes and the connections between the four low electrodes to the resistor boards (board No. 2 is not included, more resistors upstairs in the drawer if needed).
6. Check the lower current stabilizer as described earlier for the upper one.

This unit has biven trouble because of an undetected poor connection in the electronics inside the metal box but should be O. K., if the box is "shaken" a little bit. If this does not help, take the unit out of the box and unsolder the transformer and reconnect the transformer - but not high voltage - and check +6V, -6V, +75V and -75V at the places indicated on the electronics schematic (in the cabinet). When all these work the unit should respond as described for the previous one. When working put the unit back into plastic box and turn the dial to full scale.

Check to see that the vacuum is O. K. and that the big "close-off" valve in the middle of the optical bench is open.

Turn on the three black switches on the power supply. Turn the voltage control to zero. Press the high voltage button. If the circuit breaker flips off, turn it on and try again. It might do this a few times. Turn up high voltage until there is a discharge in all four arms up to about 12 mA. To adjust these values use the rheostats on the resistor rack and on the current stabilizer box. Set dial on the stabilizer to regulate to about 55 mA. Open the gas close off valve on the resistor rack (the right valve) and increase the high

voltage to keep the discharge current to about 55 mA.

Adjust the resistance in arm No. 1 (L1) by the rheostat to about 15 mA when the voltage is increased.

After about 1 minute there should be an equilibrium with a bluish-redish discharge going in all four arms. Set the discharge in all arms to be about the same (about 13-14 mA) by turning the rheostats. Check to see if the amplifier is working by putting a piece of paper in front of it - the paper should burn quickly. If not align mirror C as shown in figure 7 (see also figure 8). Put the power meter at the end of the amplifier as shown, when the amplifier is on. Adjust salt window E so the spot reaches the power meter (use heat sensitive paper) then adjust mirror C for max power (about 1 W) which corresponds to about 45 W total power.

Readjust the power meter head and mirror C again. Leave E in same place, since a change in its orientation will change the percentage of power scattered out and thereby the calibration of total output power.

#### F. Alignment of detector holder

Check (using a heat sensitive paper) to see that the beam reaches the  $45^{\circ}$  mirror. If not, move the holder until this is the case. Adjust aperture mirror D by the micrometer screws to center the hole by putting the power meter in the cooled detector's place. Move the micrometers until the power meter reads about 100 mW to 300 mW (see figure 9).

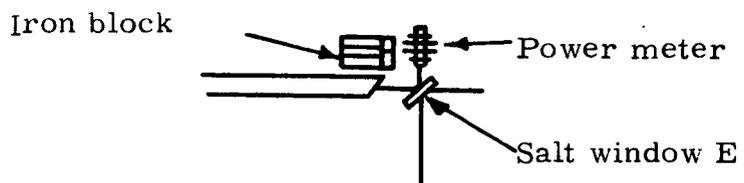


Figure 8. Mounting of laser power meter.

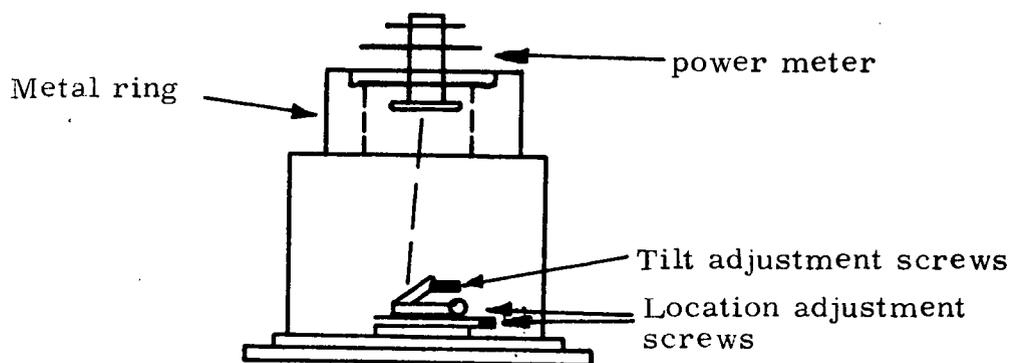


Figure 9. Centering of D

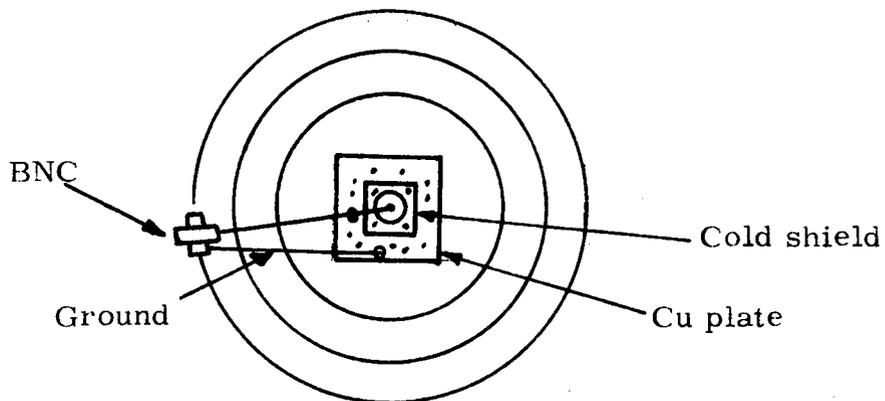


Figure 10. Mounting of the detector element

Adjust the 45° mirror:

1. Put a round plastic disk with a center hole in the thick metal ring and tape a piece of heat sensitive paper and move the whole holder until the resulting burn spot coincides with the center hole of the plastic disk.
2. Replace the plastic disk in the 1 inch long aluminum cylinder in the metal ring. Adjust loaded screws holding the 45° mirror until the beam reaches the center hole in the disk (also as observed on heat sensitive paper).

Then readjust the lower "centering" again as described previously until the beam goes vertically into the center of the holder. Fine adjustment must be made with cooled detector in place.

G. The cooled detector (see figure 10)

1. Mounting and pump down procedure

To borrow the dewar, if it is not in the lab or in Nuclear Engineering (Jim DeBoos Nuc. Eng. used it when I left) phone Joe Mudar at Willow Run.

To mount the detector element if it is out of the dewar:

1. Take the cold shield off of the copper block.
2. Fasten the copper block with the detector element so that the plastic post is close to the BNC connector on the dewar. Put some silicone grease on the plate for better thermal contact with the dewar. One of the screws should also attach a ground wire from the BNC connector.
3. Fasten the cooled shield. It can only be in one position as indicated by two matching X's. Make sure the shield is aligned with the engraved contour on the block.
4. Solder the thin wire from the detector element to the wire from the BNC connector.
5. Check the resistance (should be about 4 ohms).

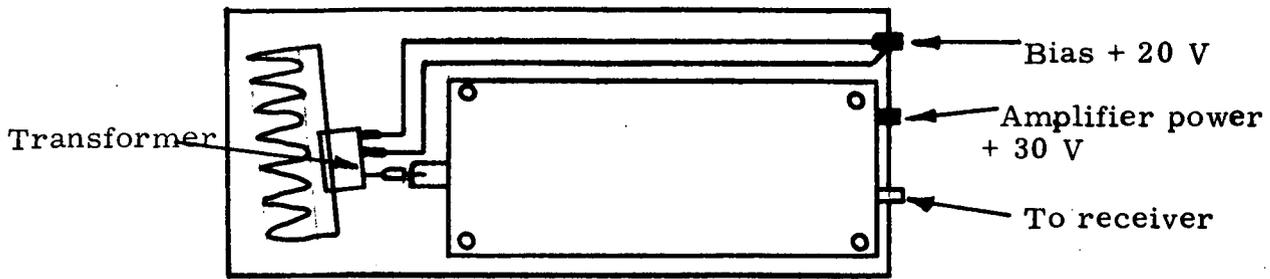


Figure 11. Detector Electronics

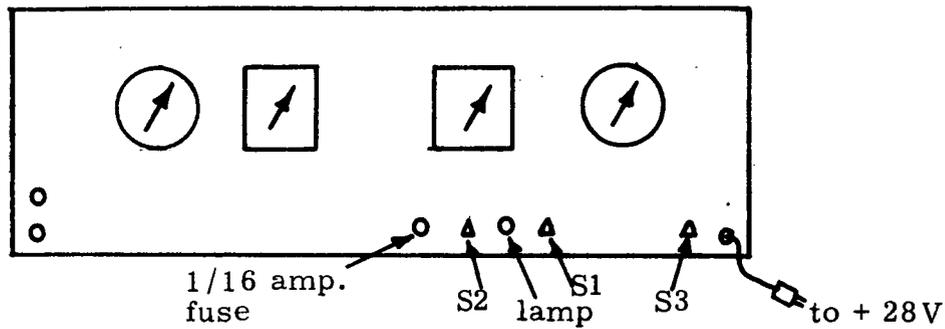


Figure 12. Battery box

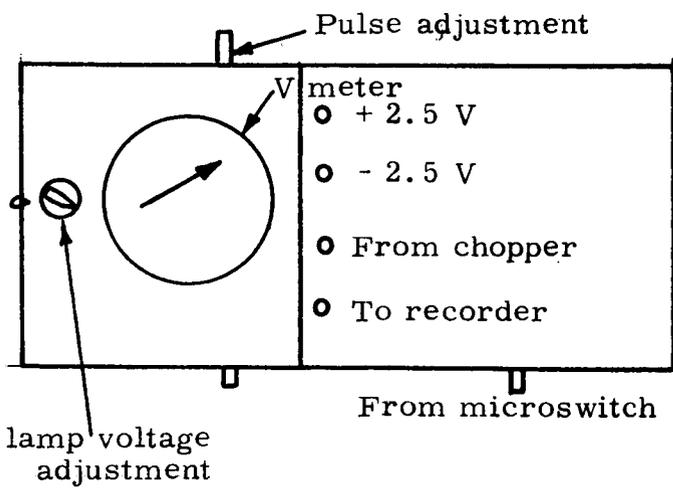


Figure 13. Pulse squaring box (top view)

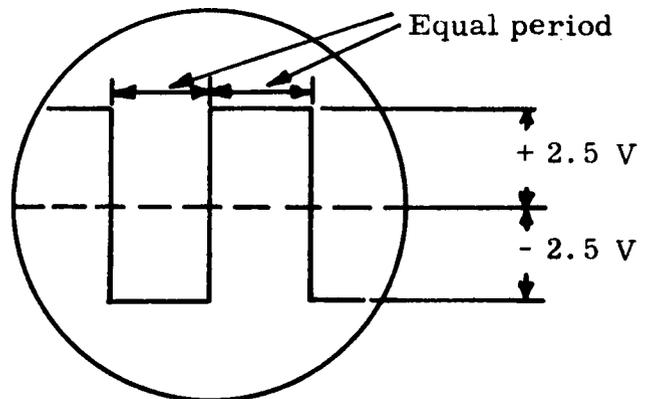


Figure 14. Scope display of Chopper

6. Fasten the outer shield (a plate with some 10 screws) to the top of the dewar.
7. Check the salt window to see that it is clear, otherwise clean it with the cleaning kit in the cabinet. Clean the o-ring groove, the dewar and the lid. Apply some vacuum grease to the o-ring and loosely fasten the lid on the dewar. Pump the dewar down using the leak detector. When the pressure is low, tighten the screws. The pressure in the dewar should be almost at the lower end of the vacuum scale after pumping with the diffusion pump for several hours.

2. Filling the dewar with liquid Helium

Start by cooling the dewar with liquid nitrogen. To do this put a funnel in the filling hole and pour in  $\text{LN}_2$  until  $\text{LN}_2$  starts to come up at the side of the funnel. About 2 liters of  $\text{LN}_2$  should be enough. Make sure the dewar is full.

Pour the  $\text{LN}_2$  out and start to transfer LHe. You can determine when the dewar is cooled down by measuring the resistance at the BNC connector. It should be about 20 M ohm, when the dewar is cooled down to  $4^\circ\text{K}$ . After this point it takes about 3-5 minutes to fill the dewar. After filling the dewar put it in holder and shield it from laser light by the manual chopper. Attach the detector electronics as described next.

3. Connection of detector electronics (see figure 11, 12)

Turn on all electronics in the rack except switch "S2" on the battery box. Attach the aluminum box with the pre-amp and the transformer to the dewar at the BNC connector.

Connect detector lead from "Detector" on the box to "Antenna" on the special purpose receiver. Connect the line from power supply, set at +30V to the pre-amp marked "amp". Be sure of the polarity.

With both switches on the battery box down, connect "Bias" on the box to "Bias" on the battery box. Turn switch S1 on and press switch S3 until you read about 20V on the meter. Switch on S2, there should be no reading on the mA meter if there still is LHe in the dewar and it is shielded for laser light. The fuse will blow for 1/16 amp which generally means that the LHe is gone. If there is no change in the mA reading, open the chopper. The meter should now show a few mA. Adjust the screw on the side of the mirror holder and the wheel at the 45<sup>o</sup> mirror mount to give max mA reading, which can be as much as 9 mA (see figure 9).

Adjust the micrometer screws on the aperture mirror holder "D" to get max reading but at the same time adjust the tilt of the mirror to yield about 9W at the end of the amplifier and make sure with a piece of paper that the two spots are close to each other at the mirror "C". About 5 mA was used for 20V bias. When laser light reaches the detector make sure the noise level on the visual display is increased and you should be able to notice when the light is chopped or not on this noise level.

### III. Data Collection

#### A. Digital voltmeter - manual chopper

Connect the digital voltmeter to the output on the receiver and set the averaging period as desired by use of the H-P oscillator.

#### B. Tape recorder - rotating chopper

##### 1. Pulse squaring circuit(see figure 13, 14)

Connect a long BNC cable from the chopper BNC to the chopper squaring circuit (in the cabinet). Connect a +2.5V and a -2.5V power supply as indicated on the box. Set the lamp voltage to about 2.2V, which should cause the lamp at the chopper to light (by means of the switch on the front). Connect "out" to a scope and adjust the dial on the side of the box to read square clean pulses of identical positive and negative length and of amplitudes  $\pm 2.5V$ . When a power supply at the output end of the amplifier with about +18V turns the chopper, connect the cable from the overriding microswitch to the side of the box and check to see that a flip on the switch results in a 1 or 1/2 second positive pulse. Write down if +2.5V is the result with the chopper open or closed.

##### 2. Recorder

Set the four channels on the Ampex tape recorder which have FM reproduce and record modules to:

- a.  $\triangleright 1V$  ( 1.5) for power output from the laser power meter
- b.  $\triangleright 2.5V$ ( 3.5) for the chopper signal
- c.  $\triangleright 5V$  ( 7.5) for the data signal
- d.  $\triangleright 1V$  ( 1.5) for bias current monitoring clip-on mA meter

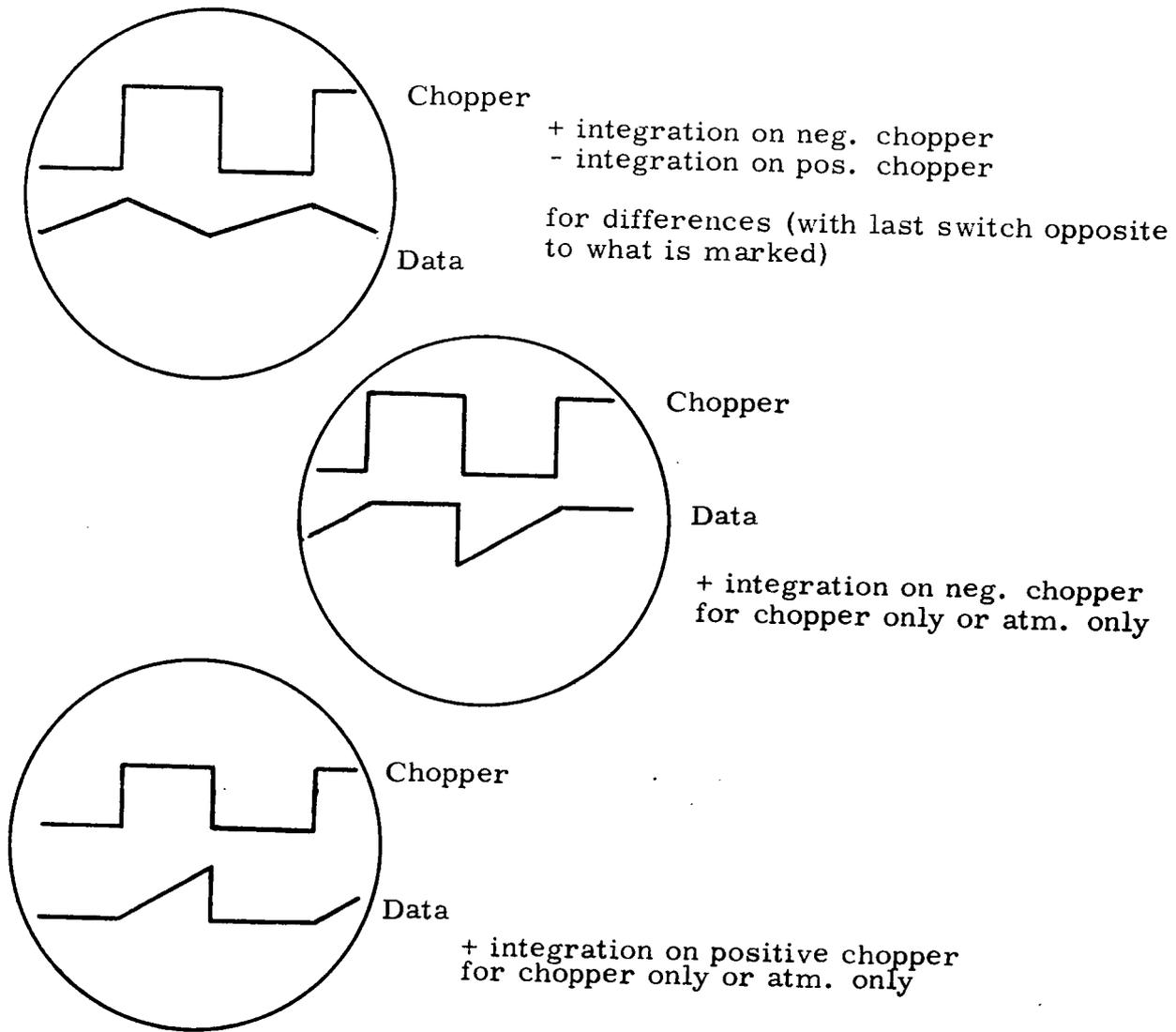


Figure 15. Scope displays of data treatment

#### IV. Data Reduction

Place the tape in the H-P recorder-reproducer in the computer run and connect:

- a. From bias channel: to "bias" on the back of the analog computer (should be stored in the cabinet) to one channel on the back of the rack of the computer (#5, probably, but check in the program).
- b. Laser power: in analogy with #3 above.
- c. Chopper: to "chopper in" on analog computer, "flag out" to a board to be plugged in the computer (should also be stored in the cabinet).
- d. Data: to "data in", "data out" to channel 2 on the back of the computer.

For further information consult with Steven Eberbach, Kim Ward, Jim Cutler.

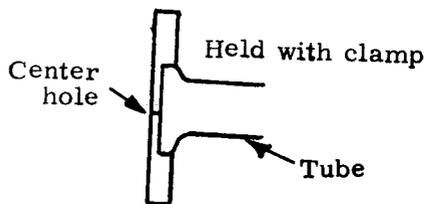
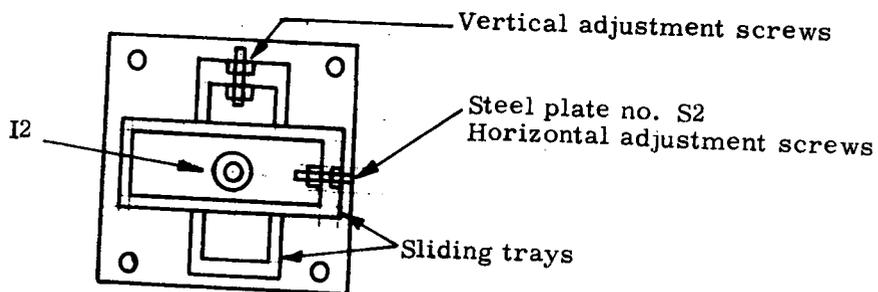
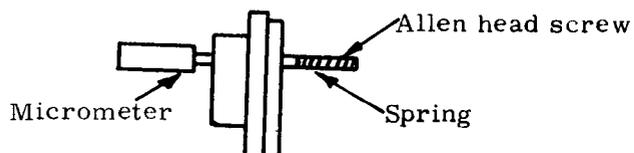
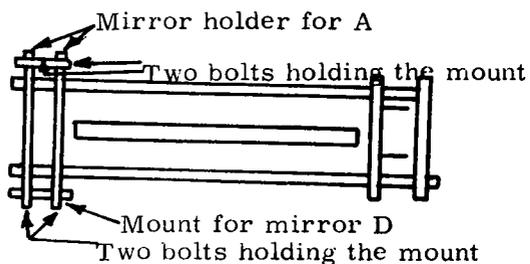
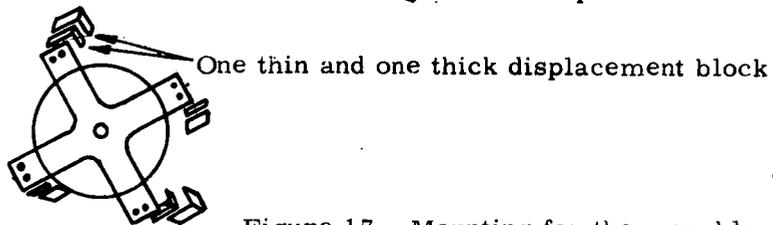
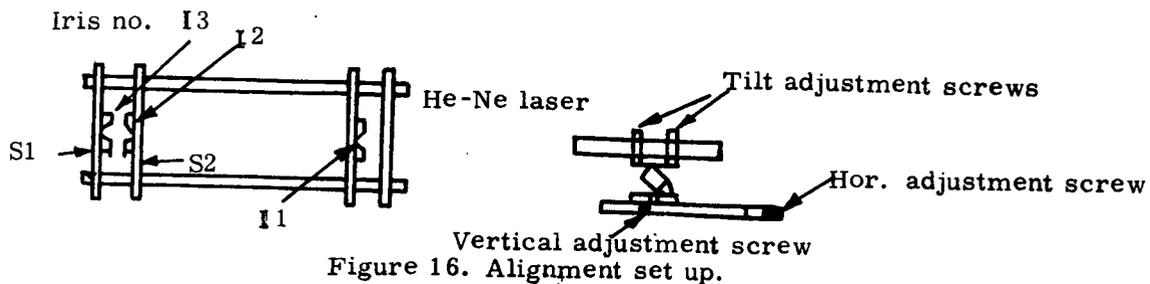
##### A. Programming of the analog computer

Connect the chopper from the recorder and the "data out" on the analog computer to a scope and depending on the setting of switch on the top of the analog computer (see figure 15).

Make sure what positive chopper and negative chopper integration refers to, i. e. does positive chopper imply that the chopper is open or vice versa.

##### B. Programming of the digital computer

1. RIM
2. BIN
3. FOCAL
4. FANDERS (in a paper box in cabinet) (load as BIN)
5. Program marked "Super prog" (load with FOCAL)



## V. Complete alignment

As a last resort the whole system might have to be realigned.

This is a tedious process. To do this procede as follows:

### A. Alignment of the fixed mirror, the movable IRIS ( 2) and the tube (figure 16-24).

1. Fasten a He-Ne laser on the sliding tray (taken from the end of the amplifier channel) and fasten the tray at the aluminum piece held on one side of the table.
2. Remove the movable mirror system by removing the eight screws holding the system - be careful not to bend the differential screw or remove the water cooling hoses. Place the small removed metal blocks so that they can be put back in exactly the same place they were taken from. (They are marked with letters).
3. Remove both mirror holder constructions holding mirrors "A" and "D" at the other end of the laser oscillator.
4. Close the vacuum for both oscillator and amplifier and remove Brewster window holders from the tubes - use gloves.
5. Open IRIS No. 2 completely.
6. Adjust the He-Ne laser so that the beam goes through I1 and I3 - can be rather difficult.
7. Adjust the fixed mirror by means of the micrometer to reflect the laser light to the opening in I3. To lessen the force on the micrometers unscrew the allen head screws on the opposite side when tightening these after alignment - be careful not to force them too much, the thread is not very good.
8. Adjust I2 by the four screws to center the IRIS at the beam.
9. Center the tube on the beam by attaching a plastic piece at each end as shown in the figure below and move the tube at the two tube holders.
10. Carefully replace the fixed mirror mount. Check that the water hoses are attached.

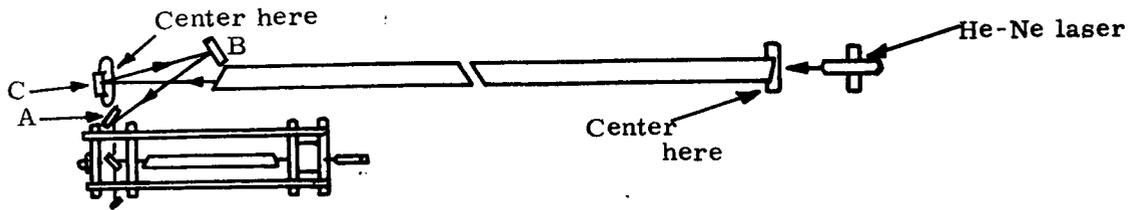


Figure 22. Alignment set up

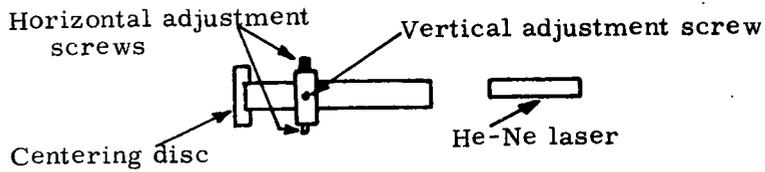


Figure 23. Alignment of amplifier section

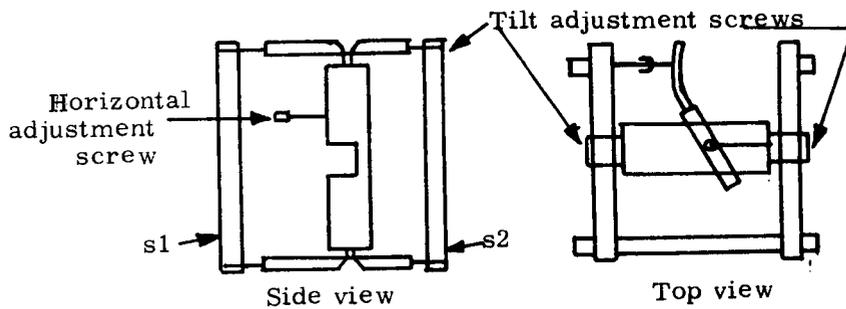


Figure 24. Beamsplitter mount

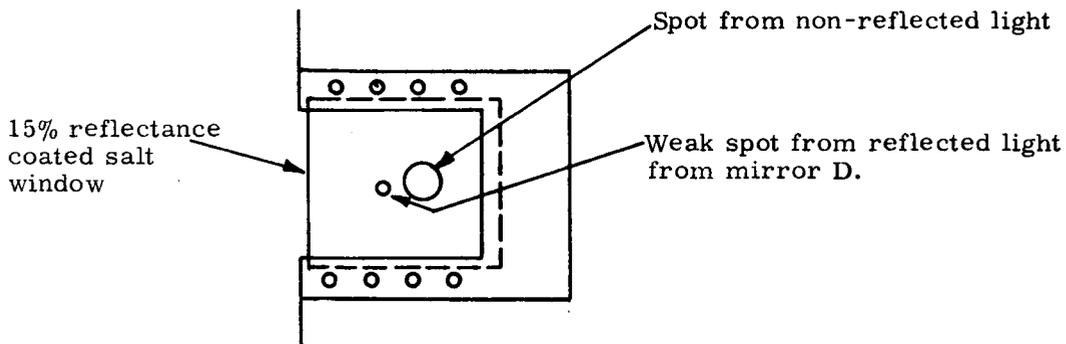


Figure 25. Image on the beamsplitter

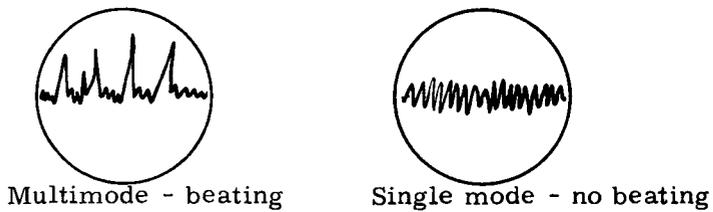


Figure 26. Visual display for single and multimode lasing

B. Alignment of the moveable mirror, the beamsplitter, the laser amplifier and the four mirrors "A", "B", "C", and "D" (figure 22-25).

1. Put the He-Ne laser and the sliding tray arrangement back at the end of the laser amplifier.
2. Adjust the He-Ne laser so that it is centered on the curved mirror "C", use the aluminum cover with a center nail to do this.
3. Adjust the He-Ne laser at the end of the amplifier to be centered on the end of the amplifier by using a piece of plastic with a center hole. Check the center at mirror "C" again. These two last steps can be rather difficult.
4. Align all amplifier sections - starting with the section closest to the He-Ne laser. Put the plastic piece at the other end of this section and center the section by means of the screws on the holder. Check centering at the other end. Clamp on next section and center this section at the open end using the plastic piece etc.
5. Align mirror "C" to reflect the He-Ne beam to approximately the center of mirror "B".
6. Put mirror "A" back and adjust mirror "B" so that the beam is approximately centered on mirror "A".
7. Adjust mirror "C" and "B" so that the reflected light goes through the center of IRIS No. 2. This adjustment can be rather difficult.
8. Adjust the beamsplitter to center the beam at the middle of IRIS I3 and do 7 again.
9. Adjust the micrometers of the moving mirror to reflect the light to the center of IRIS No. 2. Check the alignment of the tube - it should be aligned.
10. Replace holder for aperture mirror "D" and try to center this mirror by noting the reflected light on the beamsplitter surface. This reflected image should coincide with the image of the unreflected beam.

The laser system should now be aligned and ready to work - open the irises completely at first and fine adjust as described previously when the system is running using a laser power meter.

### C. Single mode operation

Since the irises are open, the laser is now running multimode. To achieve single mode operation use the cooled detector and observe the beats between the mode. Close irises I2 and I3 until no beats appear on the visual display.

The burnt pattern on a piece of paper should now be circular and only one spot, while for multimode it was several spots.

### VI. The rubber tubes

Fill the rubber tubes until the table is floating". There are two spare tubes in the back room. To use these an extension to the valve must be soldered on using the torch.

GOOD LUCK!

## References

1. Anders Daniels, "Mandel'shtam-Brillouin Scattering of CO<sub>2</sub> Laser Light from the Atmosphere as a Remote Sensing Probe," High Altitude Engineering Laboratory, University of Michigan, NASA Grant NGR 23-005-452, Report No. 004780-1-T, January 1971.